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NOVA LMC 1990 No. 1: THE FIRST EXTRAGALACTIC NEON NOVA

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ABSTRACT

IUE observations of Nova LMC 1990 No. 1, the first neon (or ONeMg) nova observed outside the Galaxy, were obtained from 17 January 1990 through March 1990, with especially dense coverage during the first 25 days of the outburst. (The "neon" nova categorization is based on the detection of forbidden Ne III-V lines in optical spectra; the ultraviolet neon lines were not detected.) During the first 30 days of the outburst, the radiative losses were dominated by the N V λ1240 and C IV λ1550 lines. The maximum ejection velocity was approximately 8000 km/s, based on the blue absorption edge of the C IV P-Cygni profile. Early in the outburst of Nova LMC 1990 No. 1 the UV luminosity alone was $\sim 3 \times 10^{38}$ erg/sec, implying that the bolometric luminosity was well in excess of the Eddington luminosity for a one solar mass object.

Keywords: Novae, ultraviolet spectra

I. INTRODUCTION

A nova was discovered in the Large Magellanic Cloud by Garradd (ref. 1) on 16.47 January 1990 at a visual magnitude of 11.5 (since a second nova was also discovered in the LMC about one month later, they are known as LMC 1990 No. 1 and LMC 1990 No. 2). *IUE* observations began on 17.95 January, within hours of announcement of the discovery. Initial ultraviolet spectra (18.05 January 1990, references 2 and 3) showed a hot continuum and strong emission lines (N V, Si IV, C IV, and Al III) with P-Cygni profiles. The P-Cygni lines had flat-bottomed absorption troughs extending to more than -6000 km s^{-1}. This remarkable spectrum and large expansion velocities are very similar to early outburst spectra of V693 CrA (Nova CrA 1981), an ONeMg nova (ref. 4), and U Sco 1979 (ref. 5).

Further evidence of Nova LMC 1990 No. 1's similarity to V693 CrA came from Dopita and Rawlings (ref. 6), who reported the appearance of forbidden neon lines in optical spectra. [Ne III] λ3868 appeared on 22 January, and [Ne V] λ3426 on 29 January. By 13 February 1990 (ref. 6) [Ne V] was the strongest emission feature in the visual spectrum. Nova LMC 1990 No. 1 was clearly a "neon" nova.

One of the most important contributions of the *IUE* satellite to the study of novae has been the identification of a subclass of objects which eject material enriched in intermediate mass elements (nitrogen to silicon, see ref. 7). As a result of the great strength of the ultraviolet and optical neon lines, these novae have come to be known as "neon" novae, although they are also very rich in other elements. Nucleosynthesis studies have shown that these outbursts must occur on ONeMg white dwarfs in contrast to the novae that occur on CO white dwarfs. These two classes of nova systems may originate from different stellar populations since ONeMg white dwarfs are expected to arise from more massive stars than the CO white dwarfs. In addition, it is now suspected that the ^{26}Al present in the solar system and detected by the Solar Maximum Mission may come from ONeMg novae. Until 1990, *IUE* had observed two fast ONeMg novae, V693 CrA, and Nova Aql 1982, and one slow ONeMg nova, QU Vul. The discovery of Nova LMC 1990 No. 1 as not only a fast ONeMg nova, but also having an outburst very similar to that of V693 CrA has important implications for our understanding of massive binary star evolution in the LMC and in the Galaxy.

II. OBSERVATIONS AND DATA ANALYSIS

As mentioned above, the first *IUE* spectra of Nova LMC 1990 No. 1 were taken on 18 January. Due to the fact that US2 shifts for other programs of the authors were fortuitously scheduled during the period 20 January through early February, we were able to arrange very thorough coverage of the outburst with little impact on the *IUE* schedule. Spectra were obtained daily during the first 10 days of the outburst, resulting in very detailed light curves.

Low-dispersion large-aperture spectra were obtained with both cameras (SWP and LWP). This paper focuses primarily on the spectrum below 2000Å. A single high-dispersion LWP spectrum was taken on 19.16 January. Superposed on the broad Mg II emission line was the characteristic LMC interstellar absorption pattern (0 to +300 km s^{-1}), showing conclusively that the object in outburst was located in the LMC.

The strong emission lines were N V λ1240, Si IV λ1400, C IV λ1550, and Al III λ1860. Additional emission lines present in early spectra of the nova include Si II λ1260,

O I λ1301, N IV] λ1486, O III] λ1666, N III] λ1750, C III] λ1909, Al II λ2670, and Mg II λ2800. The ultraviolet forbidden neon lines seen at late stages in other ONeMg novae ([Ne IV] λ1602 and λ2420) were not detected in our spectra. This is not surprising since they did not appear in either V693 CrA or QU Vul until well into the nebular stage when the density had decreased sufficiently from outburst values. The Si IV, C IV, and Al III P-Cygni lines had flat-bottomed absorption troughs extending to -7500, -8000, and -6000 km s^{-1}, respectively and emission profiles with widths (FWHM) of $\sim$ 4000 km s^{-1}. Unfortunately, geocoronal Lyman α badly contaminated the N V absorption trough, making quantitative comparison of N V with other P-Cygni absorption features very difficult.

Figure 1 shows the light curves for the total ultraviolet flux ($\lambda\lambda$1200 – 3300, excluding geocoronal Lyman α), and the N V, C IV, and Mg II lines. The 1-σ measurement error is no larger than the symbol size in the figure. The decline in total ultraviolet flux in Nova LMC 1990 No. 1 is very similar to that for V693 CrA. The N V and C IV lines are at maximum strength simultaneously with the overall ultraviolet continuum. Mg II and Al III are

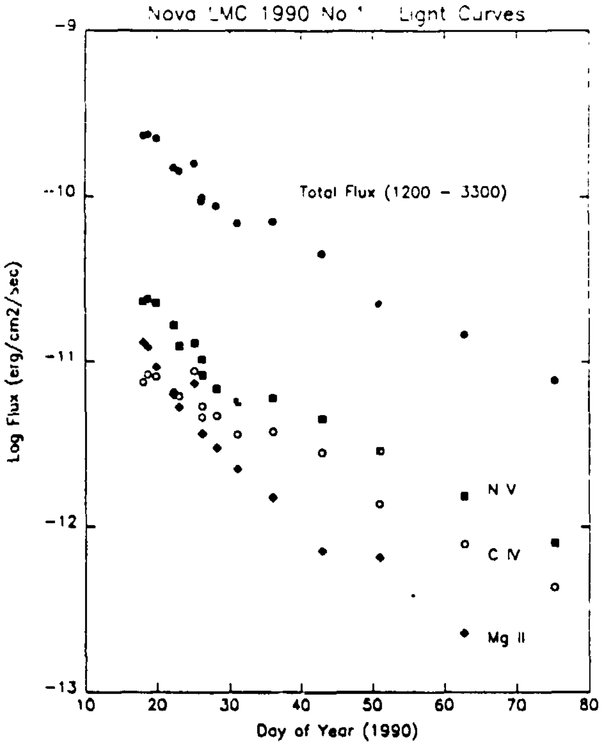

Figure 1. Ultraviolet light curves for Nova LMC 1990 No. 1. The total ultraviolet integrated flux ($\lambda\lambda$1200 – 3300) is shown with *solid circles* The light curves for the N V λ1240, C IV λ1550, and Mg II λ2800 lines are shown by *solid squares*, *open circles*, and *solid diamonds*, respectively. The break in slope in N V and C IV, as opposed to Mg II, near day 30 is due to decreasing optical depth in the Lyman continuum.

also initially strong but decline more rapidly. The neutral oxygen line (λ1301) declined even faster, being strong in our first spectrum and much weaker thereafter.

This behavior indicates that Mg II follows the decline in density as the ejecta expands while the higher ionization resonance lines, being more dependent on the ionizing radiation field, provide optical depth information. C IV had a strong P-Cygni profile until about 30 January 1990 This point in the outburst marks the transition to optically thin conditions in the ejecta. Mg II never displayed P-Cygni structure.

Figure 2 shows SWP spectra ($\lambda\lambda$1225 – 2000) on four dates. The spectra are normalized to the peak flux in N V the strongest line in the ultraviolet spectrum. The character of the spectra changed rapidly. Relative to N V (and other high- temperature lines), lines of neutral and singly ionized species faded very quickly (compare Si II λ1260 and O I λ1301 on 18 and 23 January). During this period the C IV *absorption* became narrower.

The changes in the Si IV and C IV line profiles during the entire outburst are shown in Figure 3 Note the narrowing of the C IV absorption mentioned above, the significant increase in the C IV absorption on 25 January (see below), and the gradual narrowing of the C IV emission. The development of N IV] λ1486 after about 26 January is also evident.

Assuming that the shell was ejected ballistically, so that the velocity is proportional to distance, the terminal velocity of a P Cygni profile should decrease with time as the optical depth decreases. This is due to the recession of the optically thick surface backwards through the ejecta (i.e. through more slowly moving layers), eventually reaching the completely optically thin regime. Thus the narrowing observed for the C IV absorption, is consistent with a single, rapid ejection event.

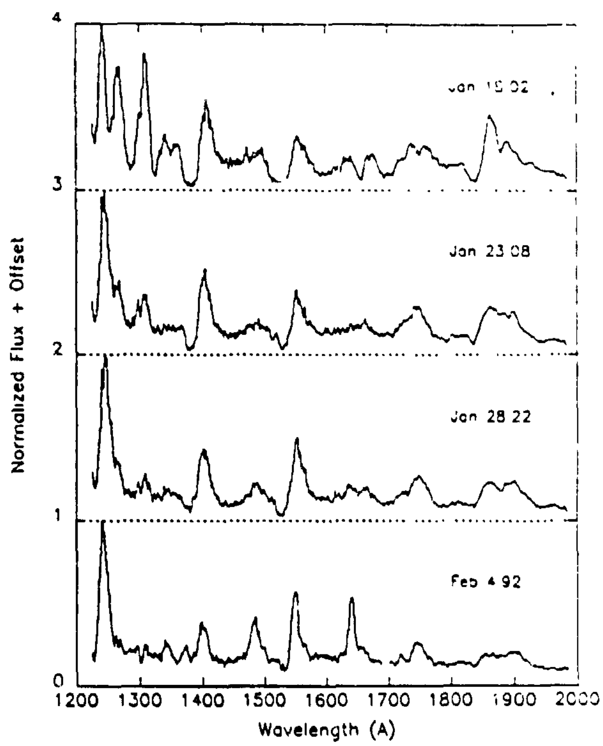

Figure 2. Four low-dispersion spectra of Nova LMC 1990 No 1 show the long-term spectral evolution in the $\lambda\lambda$1200 – 2000 region Geocoronal Lyman α has been omitted. The spectra are normalized to the peak flux in N V λ1240.

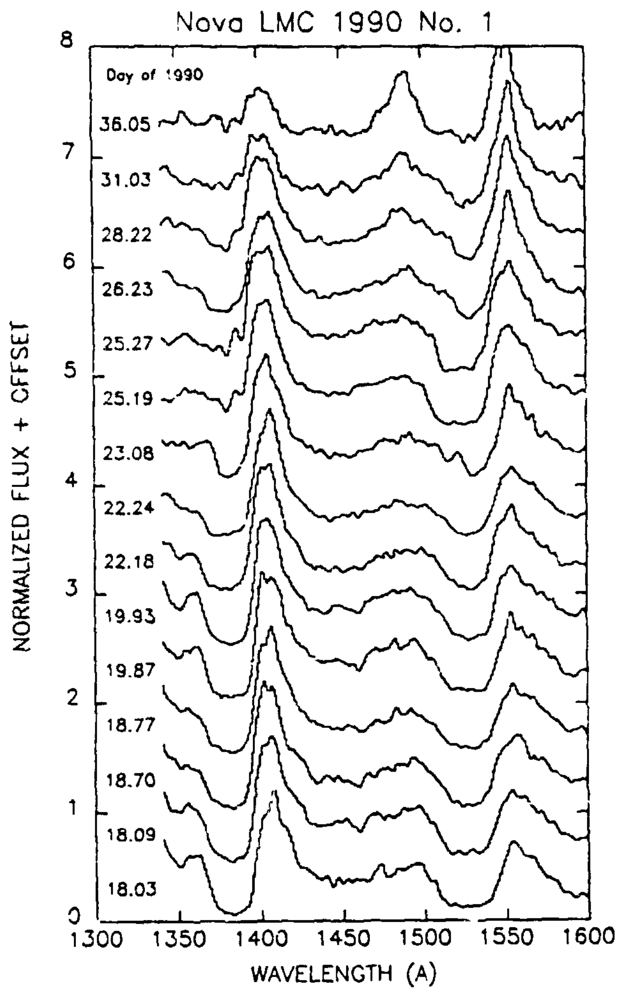

Figure 3. Gallery of low-dispersion spectra of Nova LMC 1990 No 1 showing the detailed evolution of the Si IV and C IV profiles.

III. RESULTS

Close examination of the Si IV λ1400 and C IV λ1550 line profiles indicates that a secondary ejection event may have occurred on 25 January. Between 23 and 25 January the optical depth in the high-velocity portion ($v < -4,000$ km s^{-1}) of the C IV P-Cygni absorption increased by about a factor of five. At the same time, the Si IV absorption trough disappeared, the Al III absorption trough weakened, and the total C IV, N V, and Mg II emission increased by ~ 50 percent. In fact, the total ultraviolet flux also increased by a similar amount. These latter changes are evident in the integrated and line fluxes shown in Figure 1. By 26 January the fluxes and line profiles have returned to their 23 January state.

Narrow emission features developed on top of the broad wings of C IV and He II after the ejecta become optically thin. The narrow component persists through our late-time spectra, while the broad component disappeared by the end of the *IUE* series after a steady decrease in intensity.

The interdependency of the C IV and N V emission fluxes is shown in Figure 4. The constancy of the C IV flux for $logF_{NV} > -11.0$ is likely an optical depth effect. The slope of the correlation changes at the N V flux level corresponding to the transition to optically thin conditions, which appears to be about 20 days into the outburst. This fact, taken in combination with the light curve and spectral morphology observed in the recurrent nova LMC 1990 No. 2 (ref. 8), suggests an ejecta mass 10^{-5} to 10^{-6} $M_\odot$ for Nova LMC 1990 No. 1, or about 10 to 100 times that derived for Nova LMC 1990 No. 2.

The sudden appearance of He II λ1640 between 28 January and 4 February is important (see Fig. 2) for it indicates when the Lyman continuum became optically thin and that a significant extreme ultraviolet ($100Å < \lambda < 500Å$) flux was still present three weeks into the outburst. The presence of a strong ionizing source after the shell became optically thin is further supported by the continued strength of the ultraviolet and optical He II lines at late times. The Mg II line, on the other hand, is still quite strong, indicating that the optical depth through most of the outburst was large and that the column densities were high

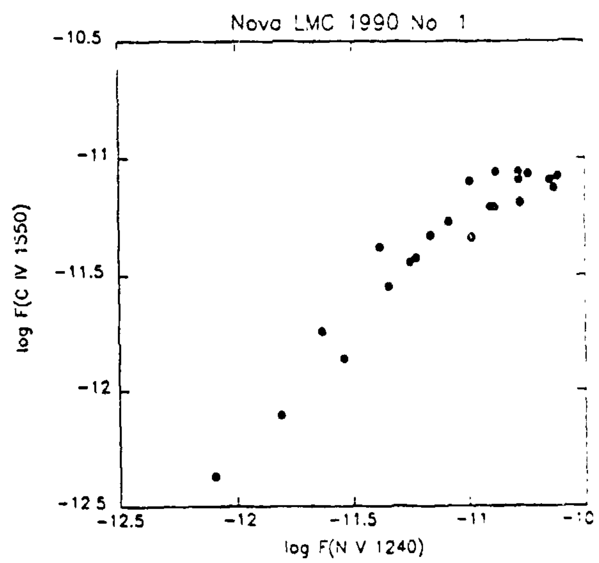

Figure 4. Comparison of N V λ1240 and C IV λ1550 fluxes The change in slope for $logF_{NV} < -11.0$ indicates the transition to optically thin conditions in the ejecta.

Unlike most novae in the Galaxy, the distance and the interstellar extinction for the LMC is reasonably well-known. Assuming a distance of 55 kpc, $E(B-V) = 0.15$ (non-30 Dor extinction), and a spherically-symmetric outburst, we can determine the absolute ultraviolet fluxes for Nova LMC 1990 No.1. Early in the outburst the ultraviolet luminosity alone (λλ1200 – 3300) is ~ 3×10^{38} erg/sec, which exceeds the Eddington luminosity for a one solar mass object. The bolometric luminosity must be at least a factor of two larger.

In contrast with Nova LMC 1990 No. 2, more of the outburst energy is transferred to the ejecta in the form of kinetic energy. Given the mass and velocity estimates, about equal amounts of energy were lost by expansion and radiation during the first 30 days of the outburst of Nova LMC 1990 No. 1, compared with less than 10 percent being mechanically transported in Nova LMC 1990 No. 2 (ref. 9).

The nitrogen abundance in Nova LMC 1990 No. 1 appears to be larger than normal for the LMC. Based on the strength of the N III-V lines throughout the outburst, especially after 30 January, it is likely that the N/C ratio is several times larger than the solar value, implying that some CNO-processed material has been ejected.

Unfortunately, the rapid decrease in line strength (see Figure 1) precluded any attempt to detect the nova in the nebular phase with *IUE* and determine elemental abundances of the ejecta. If its ultraviolet evolution continued to emulate that of V693 CrA, then it would have been about another month or so before the density had dropped sufficiently for the high-ionization forbidden lines of neon, magnesium, and aluminum to become strong. This point indicates that a follow-up study of this nova by *HST* is required in order to determine the abundances of intermediate-mass elements ejected into the interstellar medium of the LMC.

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